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MICROWAVE-CAVITY MEASUREMENT OF THE FARADAY EFFECT IN A MAGNETOPLASMA

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ABSTRACT

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For a propagating plane-polarized wave, the Faraday effect is observed as a rotation of the plane of polarization as the wave travels parallel to the magnetic field in a medium. The analogous effect in a cylindrical TE_{11m} cylindrical cavity is the coupling of the two otherwise independent orthogonal modes of the cavity. We have observed this effect in a TE_{111} cavity at 2000 Mc/sec as the magnetic field was varied from 0-1000 Oe. The magneto-active medium was the positive column of a gas discharge, located coaxially in the cavity. As expected, the coupled signal exhibits a resonance when the electron-cyclotron frequency equals the signal frequency. We are currently investigating the possibility that other resonances may exist at harmonics of cyclotron resonance.

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Previous investigators[1] have utilized Faraday Effect measurements for propagating waves to determine plasma properties, while other workers[2] have used measurement of cavity 'Q' and resonant frequency for such purposes. Portis and Teaney[3] have used cavity techniques to observe the microwave Faraday Effect in ferrite samples, but we are aware of no analogous measurements for a gaseous plasma in a magnetic field. In this paper, we discuss the manner in which the Faraday Effect manifests itself in a microwave cavity, and experiments now underway to apply such techniques to plasma measurements.

For propagating, plane polarized waves the Faraday Effect appears as the rotation of the plane of polarization of the wave as it propagates.in an anisotropic medium parallel to an externally applied magnetic field. The manifestation of the Faraday effect in a cavity is most conveniently described in another way. In an empty cylindrical cavity, any mode which is not circularly symmetric is doubly degenerate; thus, there are two orthogonal TE_{11m} modes in such a cavity. In the

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* The present work will be the subject of a thesis submitted by one of us (MTR) in partial fulfillment of the requirements for the M.A. degree.

1 J. E. Etter and L. Goldstein, U. Ill. Tech. Rept. No. 3, Contr. AF 19 (604)-524 (ASTIA Document AD 53596)

2 S. Buchsbaum, L. Mower, & S.C. Brown, Phys. Fluids 3, 1 (1960)

3 A. M. Portis and D. Teaney, J. Appl. Phys. 29, 1692 (1958)

empty cavity, it is possible to excite one of these modes without coupling to the other. If, then, an anisotropic medium is placed in the cavity, the two degenerate modes of the empty cavity are affected in two ways: (a) the degeneracy is removed (i.e. the cavity will have two different characteristic frequencies); and (b) the two modes are coupled because of the presence of the medium. One may attempt to describe this effect, as in reference 3, in terms of waves successively reflected from the ends of the cavity and which undergo greater Faraday rotation at each pass through the cavity, but it is not easy to see how to superpose these waves to obtain the mode coupling.

For purposes of the present work, we consider the two orthogonal TE_{111} modes of a cylindrical cavity. We assume that the cavity is coupled to an input transmission line which couples only to one of these modes, and an output line which couples only to the other. In the absence of an anisotropic medium, no signal will be transmitted from the input to the output. Furthermore, the condition that the modes be coupled only to the corresponding transmission lines is a geometrical one, and does not depend critically on the transmitter frequency. For convenience, we also assume that the cavity has been adjusted so that the modes are, in the absence of the anisotropic medium, degenerate. Under these conditions one may derive an expression for the output signal as a function of the applied magnetic field, for the case when there is a cylindrical plasma of diameter small compared to the cavity diameter located along the axis of the cavity, by using the method of Slater[4]. One finds that, for low magnetic field, the output power is proportional to the square of the magnetic field strength, and that as the field intensity approaches that corresponding to cyclotron resonance at the signal frequency, one expects deviations from this behavior.

In our experiments, we have used a cylindrical aluminum cavity (Fig. 1) operating in the TE_{111} mode at approximately 2000 Mc. The input line is a coaxial cable terminating in a short probe antenna, and the output line is a similar antenna, mounted in the cavity mid-plane at right angles to the first, and connected to a crystal detector mount. The signal generator is modulated at 1000 cycles, and the detector signal is amplified in a 1000 cycle twin-T amplifier and detected by a rectifier. The resulting DC signal may be read from a meter or connected to an X-Y plotter as the Y-input. The X-input is either a signal from a Hall-effect Gaussmeter or a linear time base. Due to electronic difficulties with the Gaussmeter most data have been taken with the latter arrangement using a synchronous motor to vary the magnetic field linearly with time.

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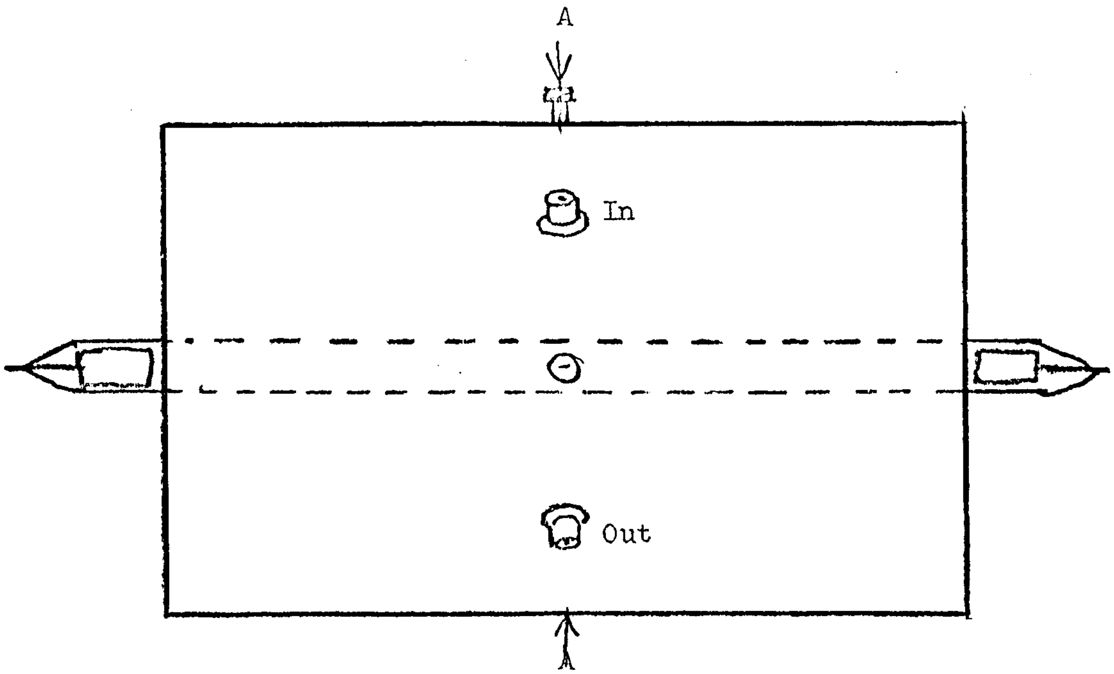
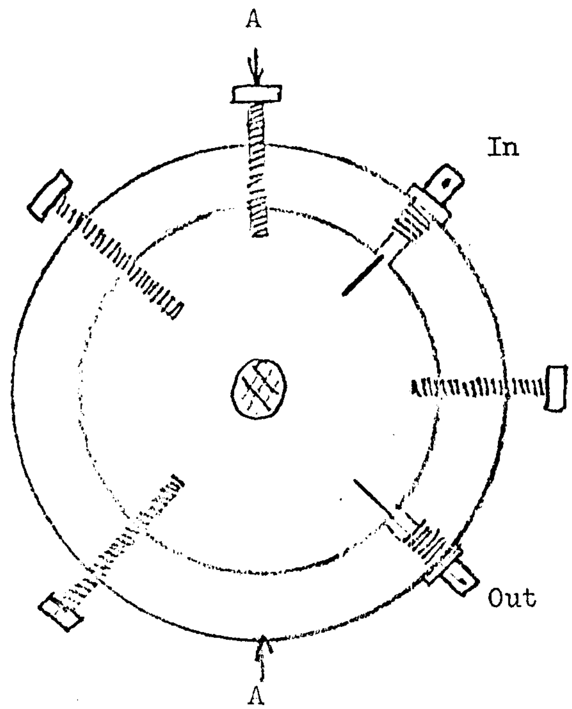
[4] J. C. Slater, Microwave Electronics, p. 57 ff. (D. Van Nostrand, Princeton, N. J. 1950). See also A. D. Berk and B. Lax, IRE Convention Record, 1953 National Convention, Part 10 Microwaves, p. 65.



Side View of Cavity



Section AA of Cavity

FIGURE 1. Diagram of the Microwave Cavity

As is evident from the figure, the cavity contains, in addition to the antennas, four adjusting screws. Two of these, opposite the corresponding antennas, serve to tune the two cavity modes to the same frequency, while the others, at 45° to these, are adjusted to decouple the modes. In tuning up, it is necessary to introduce a small amount of coupling between the modes by means of one of the decoupling screws and then adjust the tuning screws for maximum symmetrical response of the detector as the signal generator is tuned either side of maximum output. The coupling is then reduced and the tuning rechecked. Finally a condition is attained where the output is no longer coupled to the input. The magnetic field is then increased and the output signal observed as a function of the field.

Figure 2 shows a typical plot of output signal as a function of magnetic field. A pronounced deviation for steadily increasing behavior is evident near cyclotron resonance, as expected. On some runs we have observed what seems to be a 'bump' in the curve near harmonics of the cyclotron frequency, but these results have not been reproducible and are therefore not very convincing. The data shown in the figure were all taken with a section of neon sign one foot long and 13 mm. diameter, at several values of the discharge current. The pressure in the tube was approximately 7.5 Torr. Experiments are in progress to determine the effect of gas pressure, and to determine the

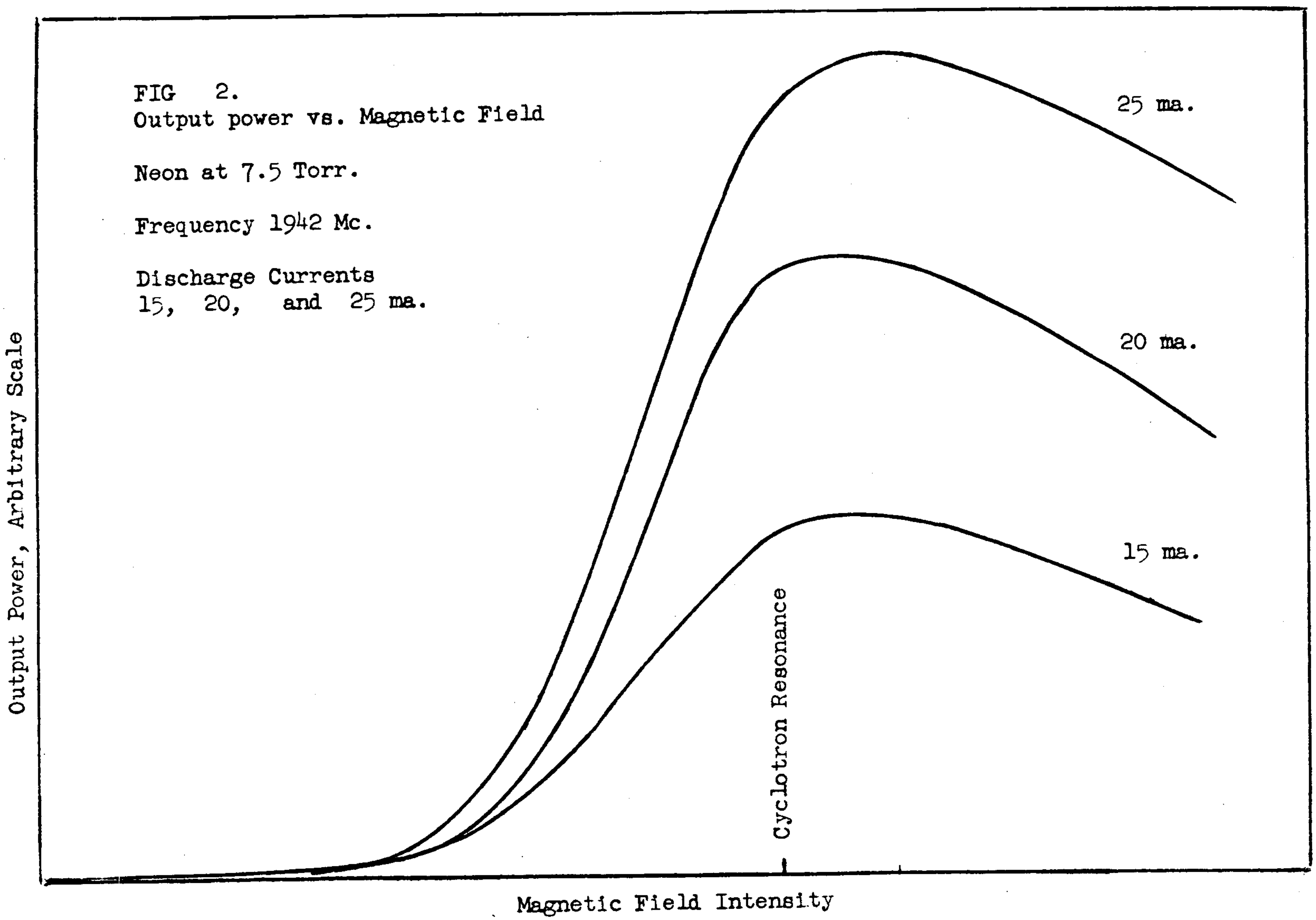


FIG 2.
Output power vs. Magnetic Field

Neon at 7.5 Torr.

Frequency 1942 Mc.

Discharge Currents
15, 20, and 25 ma.

electron density in the plasma column by the method described by Buchsbaum et al[2].

Future plans include completion of the perturbation theory calculations of the mode coupling, and if this looks promising we shall consider exact numerical solution of the problem. In addition, we are interested in applying the method to other cavity modes, such as TM_{111}; this complicated the situation because the two TM_{11} modes occur at the same frequency as the TE_{01} mode, and because the electric field no longer can be approximated across the plasma diameter by a uniform plane wave. We hope that these and other experiments still in the early planning stages will allow us to make measurements on resonances at cyclotron harmonics.